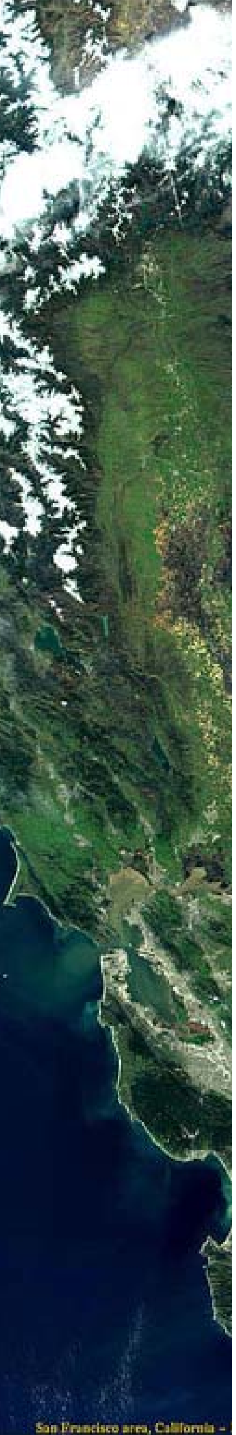

Bioenergy—Clean alternative?

Climate Action Team Forum
Fresno, California
30 May 2006

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University of California, Davis

Biomass Conversion

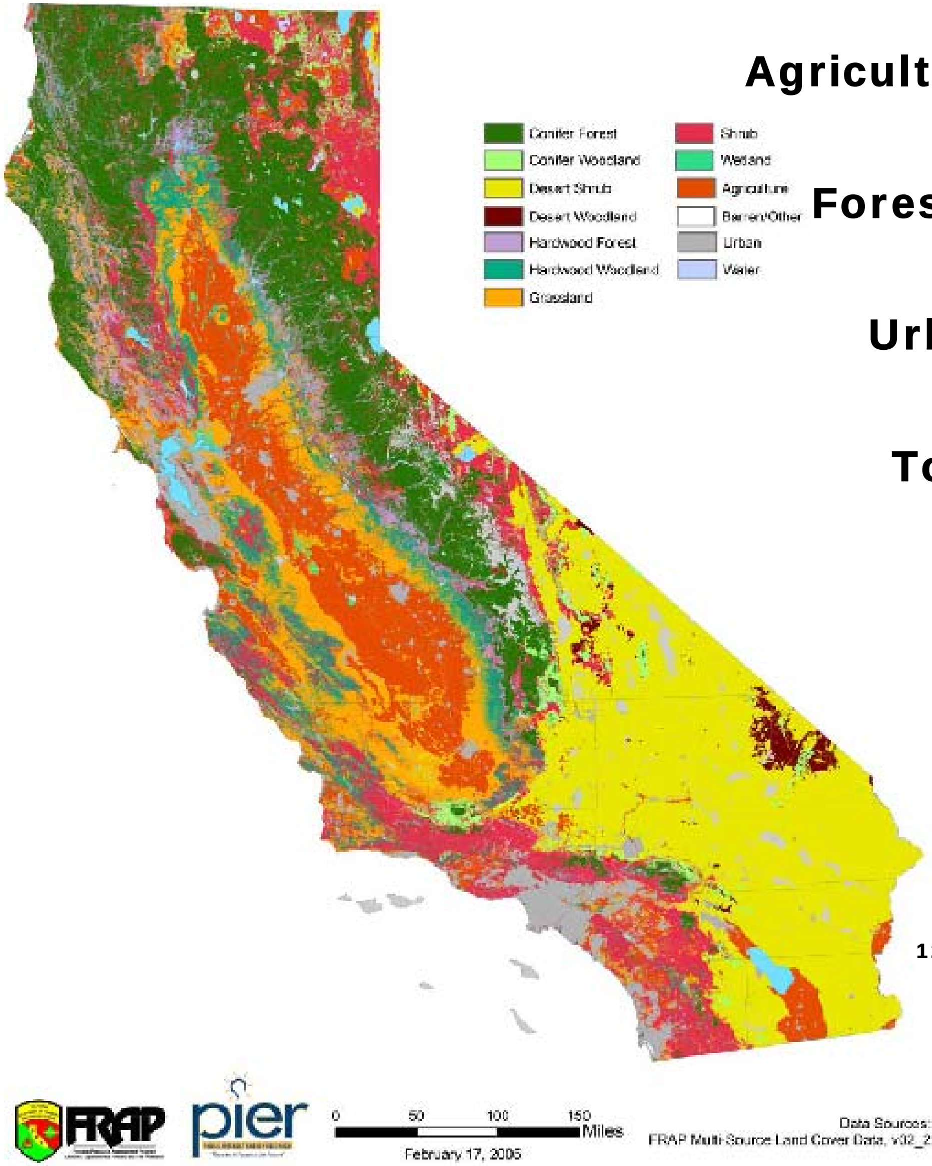
- Thermochemical Conversion
  - Combustion
  - Gasification
  - Pyrolysis
- Bioconversion
  - Anaerobic/Fermentation
  - Aerobic Processing
  - Biophotolysis
- Physicochemical
  - Esters

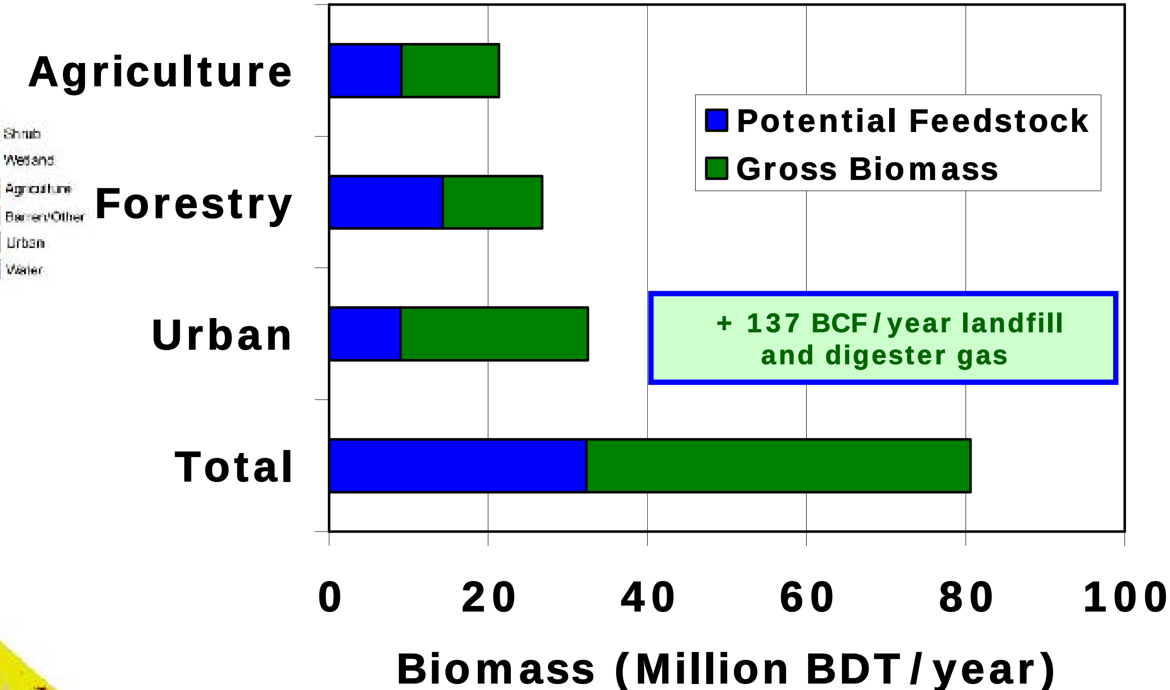
- Energy
  - Heat
  - Electricity
- Fuels
  - Solids
  - Liquids
  - Gases
- Products
  - Chemicals
  - Materials

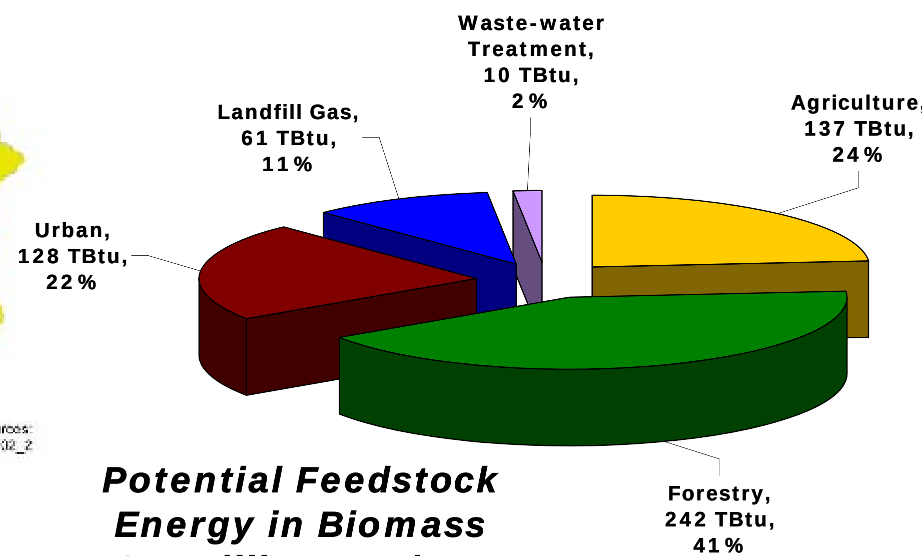
Biofuels

Fuel	Conversion Process		
	Thermochemical	**Biochemical**	**Physicochemical**
Solids	**Chars/Charcoal**	**Biosolids**	**Biomass** (incl. densified and other processed fuel)
Liquids	**Methanol** **Biomass-to-Liquids** (BTL/Fischer-Tropsch) **Ethanol** **Dimethyl ether** (pressurized) **Bio-oils** (pyrolysis oils)	**Ethanol** **Other Alcohols** **Liquified-BioMethane (LNG)**	**Vegetable Oils** **Biodiesel** (esters) **Alkanes** (catalytic)
Gases	**Producer gas** **Synthesis gas** (Syngas) **Hydrogen**	**Biogas** (incl. landfill gas, digester gas) **Biomethane** **Hydrogen**	

Biofuels can be blended with other fuels, e.g. E-85, B20







Potential Feedstock Energy in Biomass 507 Trillion Btu/year

California Biomass Resources

Total Categorical Bioenergy Potentials in California

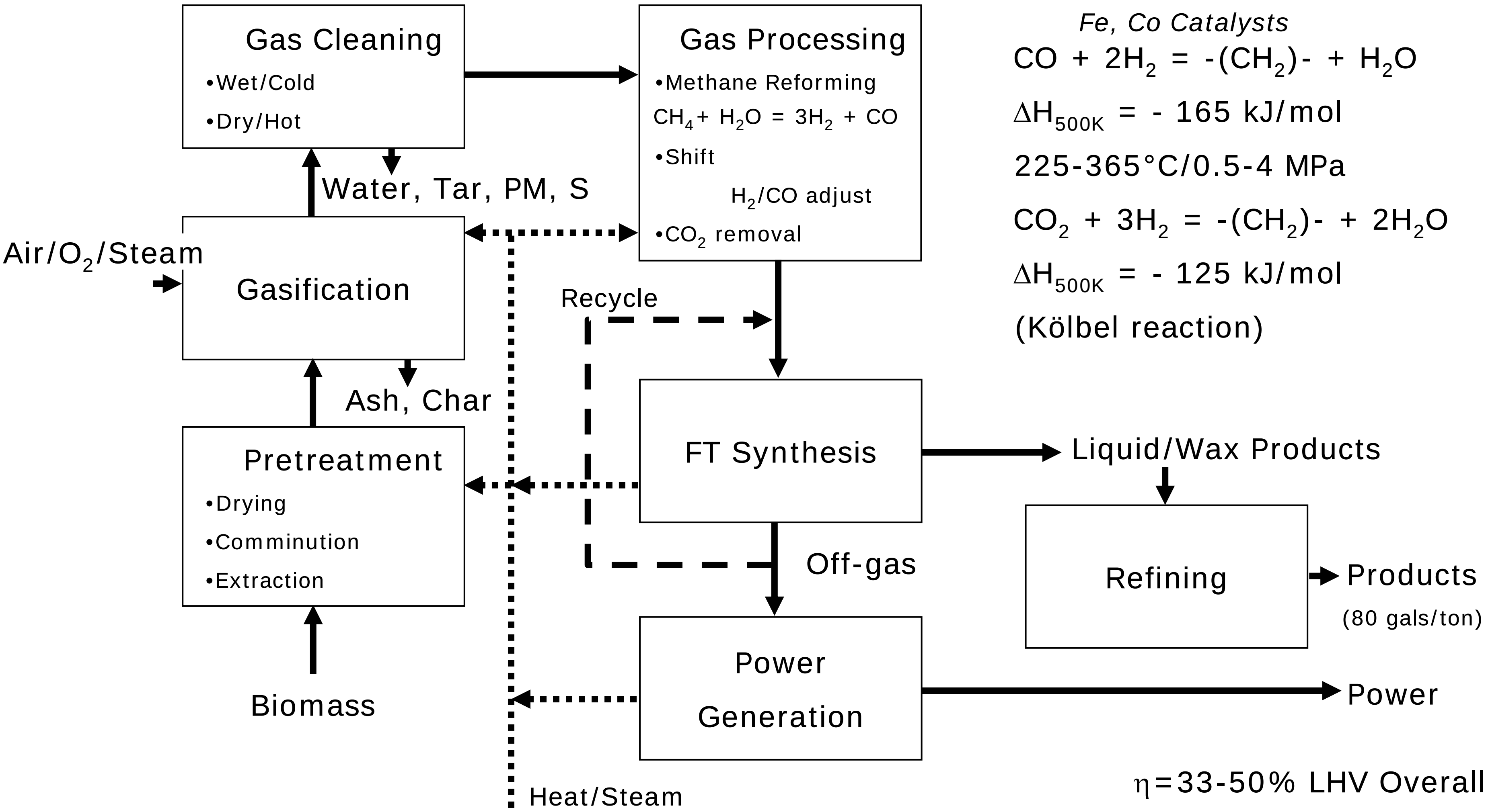
Category	Biomass (Million BDT/year)	Energy in Product (Trillion Btu/year)	Total Capacity
Electricity CHP Heat	32	118 (35 TWh) 230	4,650 MWe 9,050 MWt
Heat	32	350	11,700 MWt
Biochemical Biofuel	32	188	2.3 BGY ethanol equivalent
Thermochemical Biofuel	27	250	1.7 BGY diesel equivalent
Biomethane	5 + Landfill gas and WWTP	106	106 BCF/y methane
Hydrogen (bio + thermal)	32	305	2.5 Million tons/y

Current California consumption:
16 billion gallons gasoline + 4 billion gallons diesel = 2,500 Trillion Btu/y direct energy content
300 TWh/y electrical energy = 1,024 Trillion Btu/y direct energy

Challenges for Cellulosic Fermentation

- Cost of enzymes
  - Corn grain: 18 lbs per gallon ethanol—
    1 g protein per gallon
  - Corn stover: 30 lbs per gallon ethanol—
    100 g protein per gallon ($5 enzyme cost per gallon of ethanol)
- DOE contracts awarded to Novozymes and Genencor in 2000
- Intent to achieve enzyme cost of $0.10 per gallon ethanol or less
  - Reduced enzyme loading (achieved 2.5 to 6X reduction)
  - Reduced cost of enzyme (achieved 8X reduction)
- Overall cost reduction reportedly 20 – 30X to date
- New approaches include controlled activation and overexpression of cellulase within genetically modified plants (e.g. Farmacule/QUT modification of sugar cane).

BTL: Biomass To Liquids



Fischer-Tropsch Synthesis

Fe, Co Catalysts

$CO + 2H_2 = -(CH_2)- + H_2O$

$\Delta H_{500K} = -\ 165$ kJ/mol

225-365°C/0.5-4 MPa

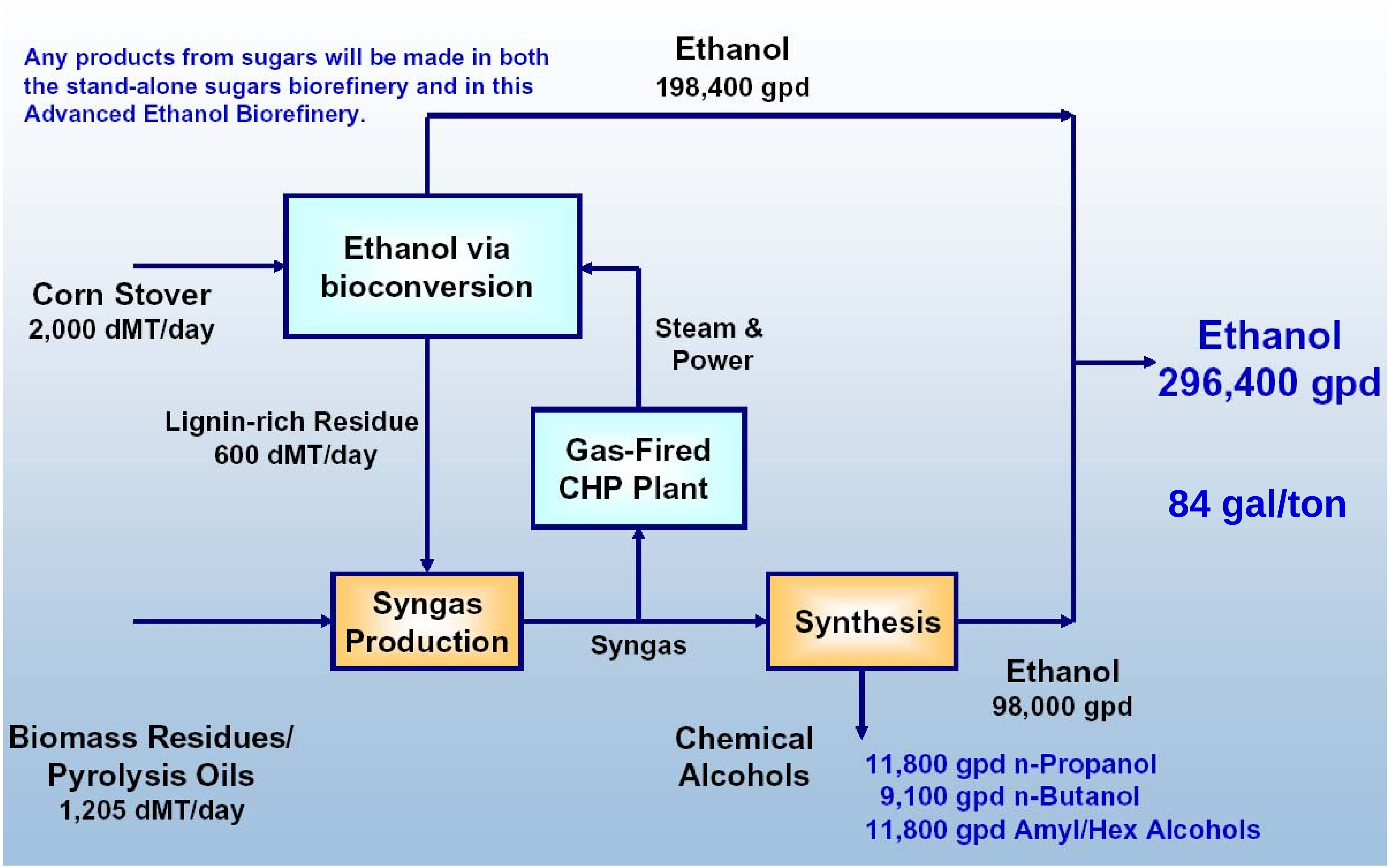
$CO_2 + 3H_2 = -(CH_2)- + 2H_2O$

$\Delta H_{500K} = -\ 125$ kJ/mol

(Kölbel reaction)

η=33-50% LHV Overall

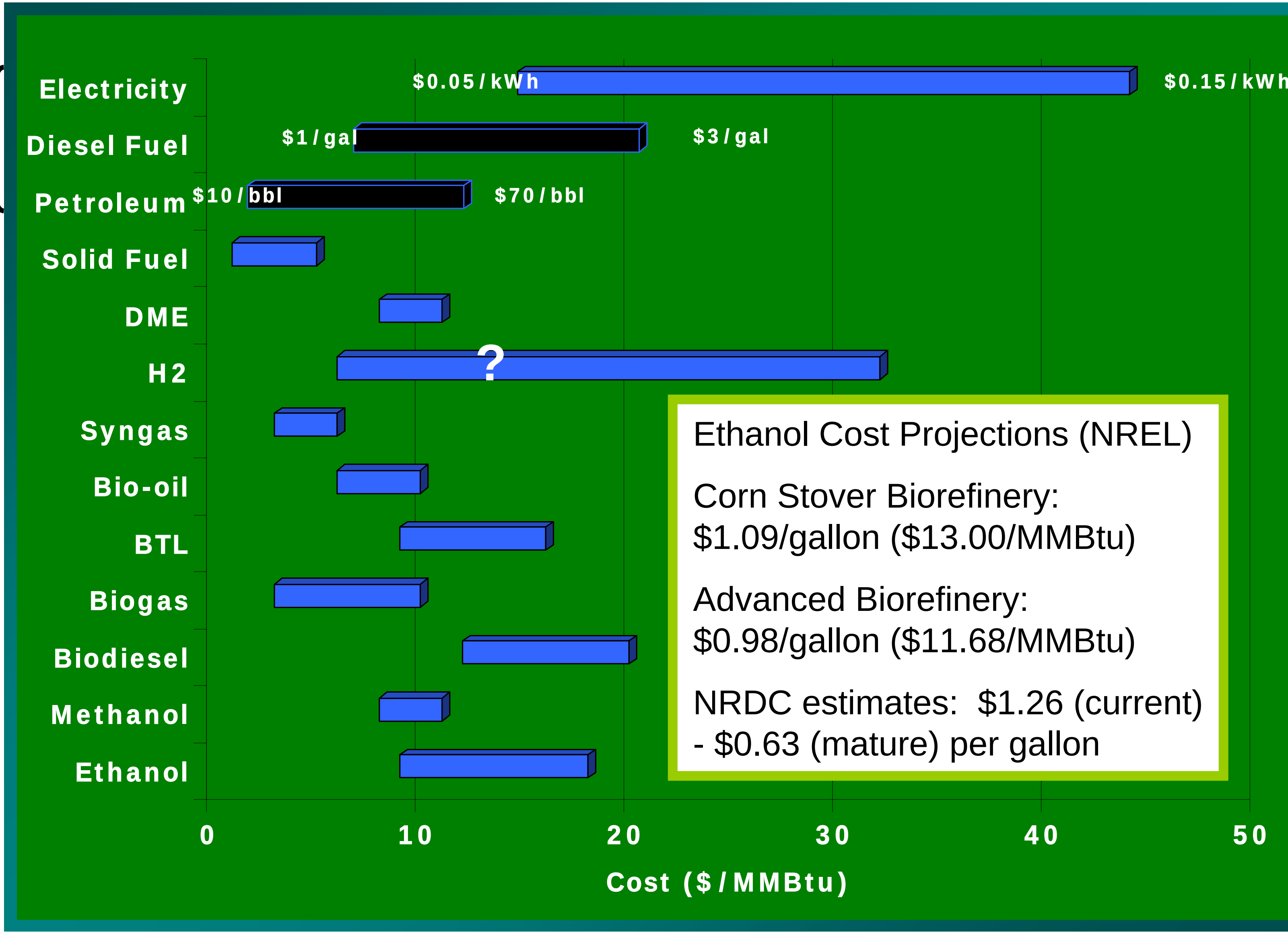
Advanced Integrated Biorefinery



Source: Bain, 2005

Biofuel Production Costs

Compare:



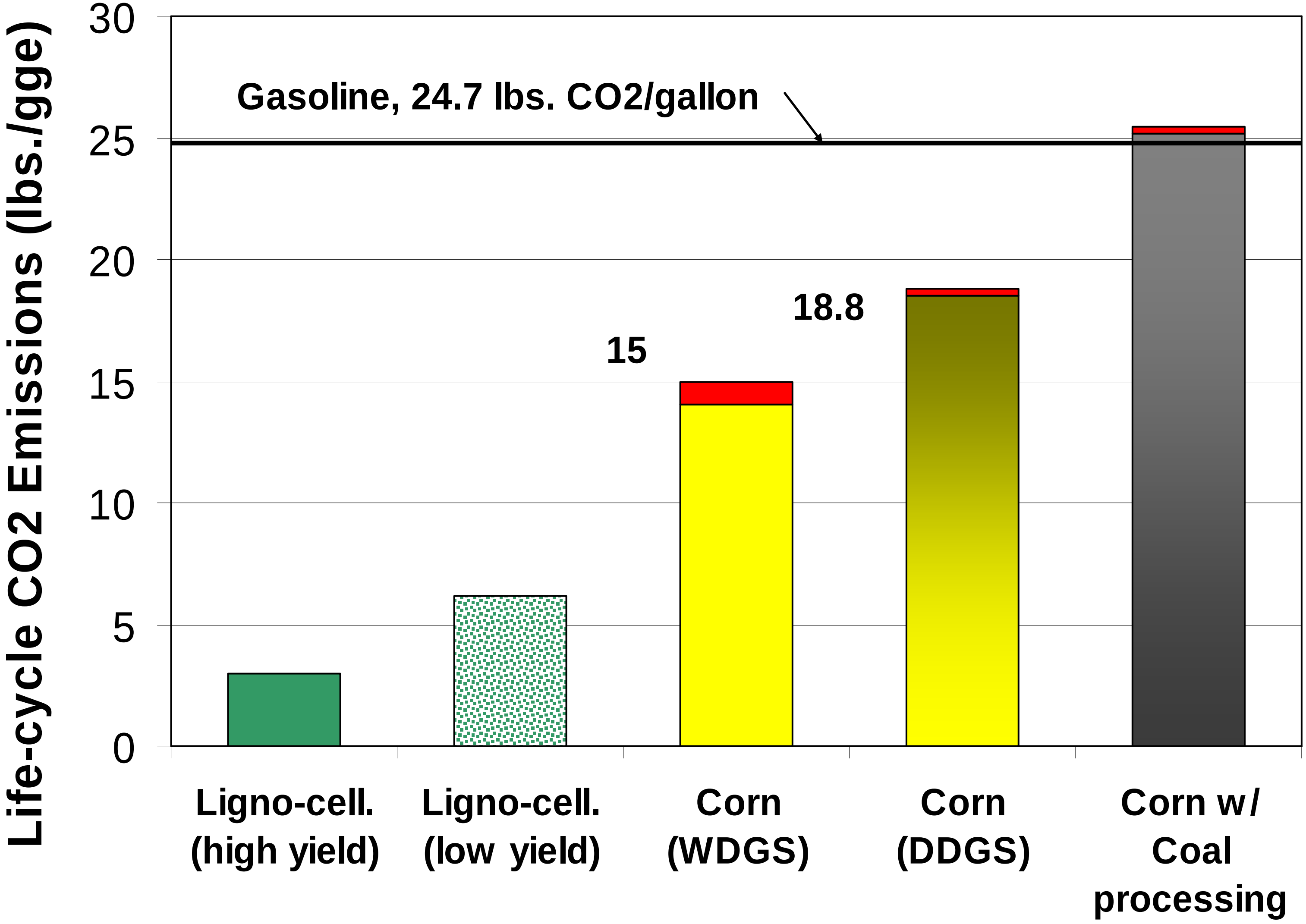
Ethanol Cost Projections (NREL)

Corn Stover Biorefinery:
$1.09/gallon ($13.00/MMBtu)

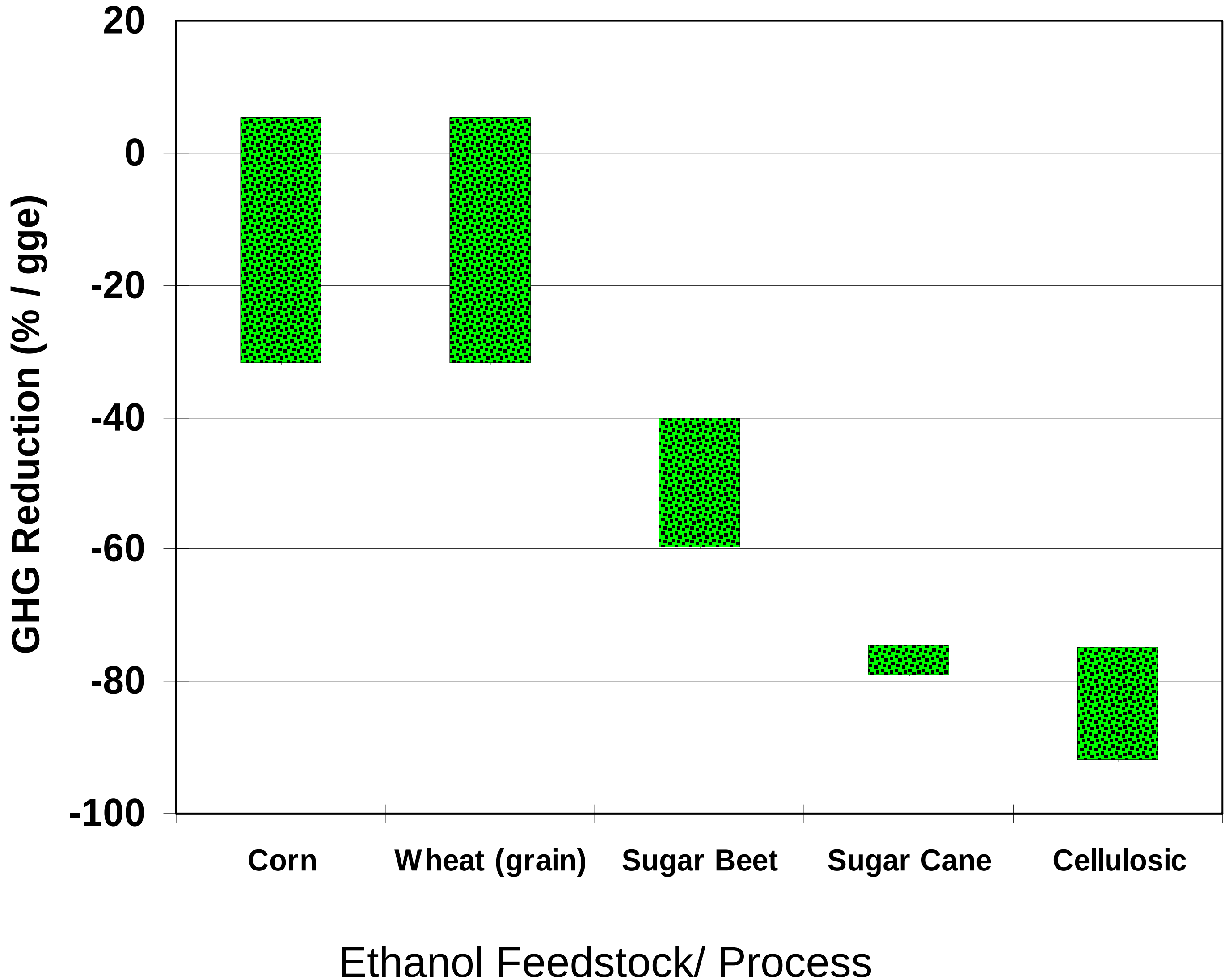
Advanced Biorefinery:
$0.98/gallon ($11.68/MMBtu)

NRDC estimates: $1.26 (current) - $0.63 (mature) per gallon

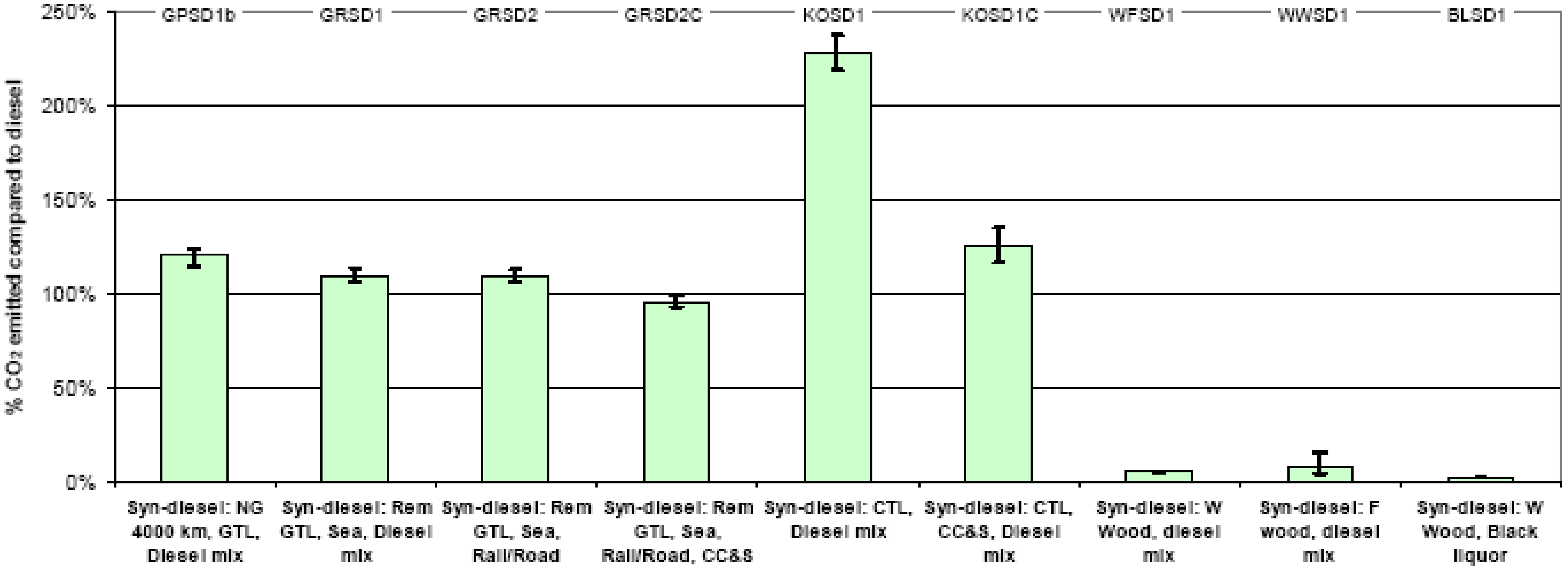
Life cycle CO_2 emissions for ethanol



Potential GHG reductions for ethanol from various feedstocks



CO_2 emissions for syn-diesels



WELL-TO-WHEELS ANALYSIS OF FUTURE AUTOMOTIVE FUELS AND POWERTRAINS IN THE EUROPEAN CONTEXT (May, 2006)

http://ies.jrc.cec.eu.int/media/scripts/getfile.php?file=fileadmin/H04/Well_to_Wheels/WTT/WTT_Report_030506.pdf

Conclusions

- In-state biomass resources are sufficient to supply a major fraction of transportation fuel or electricity (~10% of current demand, higher with improved efficiency/conservation)
- Feedstock supply infrastructure needs to be developed for large scale increase in bioenergy in California.
  - Improved collection, processing, transportation, storage, handling, separation
  - Improved access to resources
  - Long term contracting
  - Quality control
- Commercial scale demonstration required to verify technology, energy benefits, and economic and environmental performance. Full LCA comparing alternatives yet to be completed. Air quality impacts uncertain. Major opportunities to reduce GHG emissions.
- Cellulosic fermentation still not fully commercialized for production of ethanol
- Other technologies such as BTL (FT), renewable electricity, likely to emerge over the near term for transportation energy—thermochemical and biochemical routes may be integrated to advantage into advanced biorefineries
- Market infrastructure not well developed for a number of bioenergy options: grid connected-DG, CHP, E-85, biodiesel, biomethane
- Need for sustained basic research on all fronts and increased education and outreach
- Need for enduring policies, long-term incentives, efficient economic drivers